AR-009-266

DSTO-RR-0046

# Bonded Repairs to RAN FFG Superstructure-Strain Gauge Data Analysis

B.P. Phelps



DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

# Bonded Repairs to RAN FFG Superstructure-Strain Gauge Data Analysis

*B.P. Phelps*

**Ship Structures and Materials Division**
**Aeronautical and Maritime Research Laboratory**

DSTO-RR-0046

## ABSTRACT

Two adhesively bonded carbon fibre patches have been applied to the upper deck of HMAS SYDNEY, an FFG7 Class Frigate, to determine their effectiveness in overcoming fatigue cracking problems in the aluminium superstructure. Strain measurement trials were conducted before and after the patch application to determine their effect on stress levels in the superstructure. An analysis procedure based upon the relative normalised RMS strain value is proposed and validated, and is then used to assess the effects of the patches. A reduction in strain levels is observed along the sides of the patches and in other areas in the necked region of the superstructure, while there is an increase next to either end of the patches. The patches are seen as an effective means of reducing stresses at areas of higher stress and of transferring the load to the ends of the patches where stresses are lower. The effect of a weld repair to a crack on the starboard side of 02 deck, which was affected between the two strain measurement trials, is seen to cause much larger changes in relative strain levels on that side of the ship. Recommendations in relation to the conduct of further trials are provided, including; the need to conduct in high sea states to ensure suitably strain high levels, a dedicated trials period, the need to obtain directional wave height spectra and enhancements to the data analysis software. Further analysis using the Finite Element Method is also recommended.

**RELEASE LIMITATION**

*Approved for public release*



DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

*Published by*

*DSTO Aeronautical and Maritime Research Laboratory*
*PO Box 4331*
*Melbourne Victoria 3001*

*Telephone: (03) 9626 8111*
*Fax: (03) 9626 8999*

*AR No. 009-266*
*June 1995*

**APPROVED FOR PUBLIC RELEASE**

# Bonded Repairs to RAN FFG Superstructure-Strain Gauge Analysis

## Executive Summary

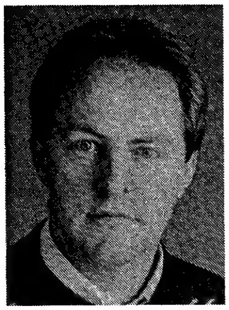
During March and April 1993 two adhesively bonded, carbon fibre patches were applied to the upper deck of the aluminium superstructure of HMAS SYDNEY, an FFG7 Class Frigate. The patches were applied to the highly stressed necked region of the superstructure around frame 196. Strain monitoring tests were carried out on SYDNEY to determine the effect of the patches in redistributing stresses within the superstructure. The superstructure of was monitored during normal operations using foil resistance strain gauges both before and after application of the patches, so that the changes in stress levels could be determined.

Insufficient sea state data was available to enable strains to be related directly to sea state and in particular wave height, so strains could be compared on a relative basis only. That is the data was first scaled, or normalised, in relation to a reference strain gauge, so that any relative changes between the pre- and post-patch trials could be identified. This method of analysis was verified by first comparing two pre-patch trials and also two-past patch trials and it was determined that for most cases where conditions, i.e. sea state, ship speed and heading, were fairly similar the error was less than five percent. Where there was a large variation in conditions, e.g. 14 knot speed and 2.5 metre significant wave height variation, the error was generally less than 10%.

The analysis showed that the patches are an effective means of reducing the strains, and hence stresses, at the midspan of the patches and in other areas around Frame 196 at the forward end of the necked region of the superstructure, and of transferring the load to the ends of the patches. A reduction in strain levels of around 10% to 15% alongside and away from the patches and an increase of about 20% immediately next to either end of the patches was observed. The weld repair of a crack on the starboard side of 02 deck, carried out between the strain measurement trials, has influenced the results and much larger changes in strain levels are indicated on the starboard side.

# Author

**B.P. Phelps**
Ship Structures and Materials Division



*Bernie Phelps commenced a cadetship with the Department of Defence in 1984 and graduated from University of NSW with B.Eng Naval Architecture (Hons) in 1986 and from University College London with MSc Naval Architecture in 1988. He was employed with the Directorate of Naval Architecture in Canberra in 1987 and 1989 and from late 1989 to April 1992 was the Hull Liaison engineer with the RAN New Submarine Project in Malmö, Sweden. In mid 1992 he started with the then Materials Research Laboratory analysing results of hydrodynamic load trials on RAN Ships and now leads a small team in the analysis and numerical modelling of hydrodynamic loads and ship's structural responses.*

## CONTENTS



## List of Figures



## List of Tables

# 1. Introduction

During March and April 1993 two adhesively bonded, carbon fibre patches were applied to the upper deck (02 deck) of HMAS SYDNEY, an FFG7 Class Frigate. The patches were applied so as to determine their effectiveness in overcoming the fatigue cracking problem of the aluminium superstructure and to establish that such technology could be successfully applied outside a laboratory environment. The latter of these two aims was successfully achieved and is reported in several articles, for example see References 1 through 3. The aim of the current report is to outline the analysis that has been carried out in the determination of the patch influence and to present the results of this analysis.

# 2. Strain Monitoring Trials

Prior to the application of the patches the superstructure of SYDNEY was monitored during normal operations using foil resistance strain gauges at selected locations on the ship. A total of twenty strain gauges[1] were used to monitor strains and the locations of these are detailed in Table A1 of Appendix A, and are depicted in Figure 1. Gauges 1, 19, 20 and 21 were arranged in a full Wheatstone's bridge configuration with one active gauge each on port and starboard sides. These gauges were then connected to the bridge such that the recorded strain was either the average of the two active gauges (i.e. longitudinal bending) or the average of the difference between the two active gauges (i.e. lateral bending). Trials were conducted before and after the application of the patches so that the recorded information could be compared to establish the effect of the patches on stress levels at the monitored locations.

The trials were conducted off the east coast of Australia with the pre-patch trials occurring during the period from 30 Nov 1992 to 3 December 1992 and the post patch trials from 14th to 16 May 1993. The trials each consisted of a 27 minutes data collection period during which time the strain data was recorded using the AMRL developed data acquisition system. The ship's speed, relative heading to the predominant seaway, estimated sea state and other observations were recorded. These observations are provided in Table A2 for the pre-patch trials and Table A3 for the post-patch trials.

---

[1] It will be noted that strain gauges were installed in either a full bridge or half bridge configuration. For the purposes of this report the term 'gauge' will be used to refer to the bridge configuration rather than an individual strain gauge.

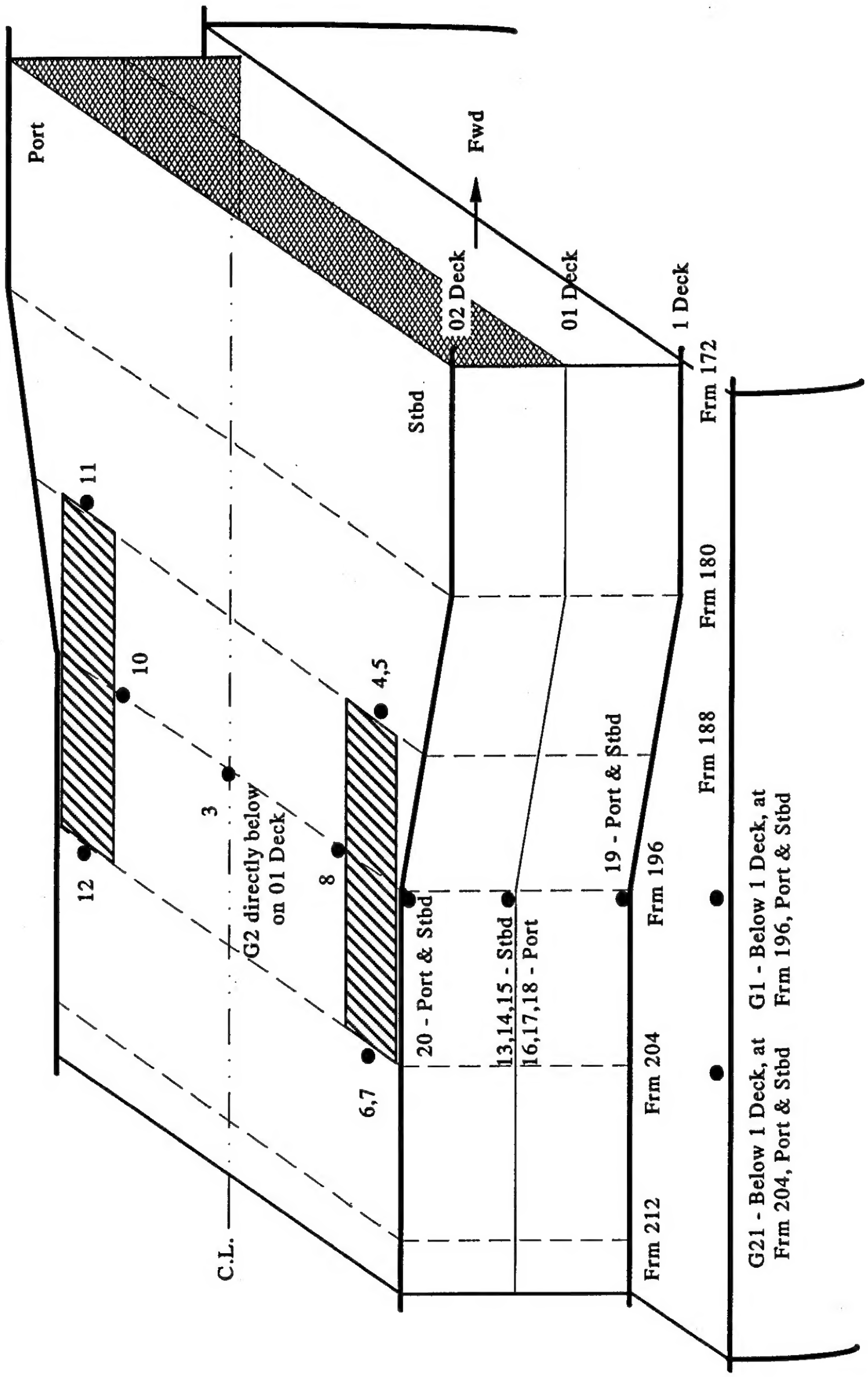



*Figure 1: Strain Gauge Locations - HMAS SYDNEY.*

The data acquisition system can digitise up to 32 channels of data, with a user-selectable sample rate. For the trials a 20 hertz sample rate and ±5V data voltage window were used. The analogue-to-digital conversion has a 4096 bit digital range which provides a voltage resolution of 2.44 mV/bit and when the strain gauge sensitivity is taken into account this enables a strain resolution of around 0.2με/bit for the full bridge configuration and 0.4με/bit for the half bridge configuration.

Trials were conducted during Navy manoeuvres as part of normal operations and so it was not always possible to achieve steady conditions for the full 27 minutes of each data collection period. This means that not all of the data collected can be used for the purpose of pre- and post-patch comparisons as steady and similar conditions are required to enable valid comparisons to be drawn. During the post-patch trials more ship time was able to be dedicated to the conduct of the trial and so a greater proportion of data is available for the comparison. Of the data collection runs detailed in Tables A2 and A3 only those runs where steady speed and heading prevailed are used for the analysis described in this report.

# 3. Data Analysis and Comparison Procedures

As the sea conditions are continuously changing and no two wave records in the same set of data are alike, let alone when the recordings are months apart, it is not possible to directly compare individual results for the pre- and post-patch trials. In order to draw valid comparisons between the pre- and post-patch data records it is therefore necessary to reduce the data to a common baseline. Ideally this would be done by finding the linear relationship between wave height and strain response, i.e. Response Amplitude Operators or RAO's, but as there was no accurate wave height measurement simultaneously with strain measurement (visual observations only) it is not possible to analyse the data directly in terms of response to wave loading. Sea conditions are only available in terms of a 'Sea State' category which is really only a notional description and provides no real information about the prevailing conditions. This lack of detailed knowledge of the sea conditions imposes severe restrictions on the type of analysis that may be carried out.

In order to quantify the effects of the patches 'normalised' RMS strain values are used. The RMS value of a particular strain record is a measure of the average strain amplitude during the measurement period and

$$\text{Ave strain amplitude,} \quad \bar{\varepsilon}_a = 1.25 \times \text{RMS value}$$

To obtain a common baseline for the data, the recorded strain values, or subsequent processed data, are 'normalised' by dividing the strain value by either the RMS or variance of the strain data for a reference gauge. This has the effect of scaling the data in relation to the reference gauge so that the relative differences for the pre- and post-

patch data can be obtained. Gauge 19, which measures pure longitudinal bending strain at 1 Deck, is used as the reference gauge throughout. It was originally intended to use gauge 21, which is furthest from the patches and closest to midships, as the reference gauge. However for the final two runs of the post-patch trials, 05161014 and 05161044, the relative magnitude of gauge 21 strains dropped to about half of what they had been in all previous cases. The reason for this change is unknown but it is consistent with debonding of one of the active strain gauges. It was necessary therefore to use gauge 19 as the reference gauge even though it is located adjacent to the knuckle at frame 196.

The method of comparison assumes that the process is linear and that the patches have negligible effect on the relative level of strain at gauge 19. This is not exactly true but it is believed that the patches have little effect on the overall section modulus and that gauge 19 is sufficiently remote from the patches so as to avoid any local effects. Any error due to these assumptions is believed to be small and a validation procedure is used to check the probable level of error involved.

For a comparison of RMS values to provide a reliable indication of the change in stress levels it is necessary that there be reasonably high correlation between the individual strain gauges and the reference gauge. If the correlation is low then there is no reason to expect a linear relationship between the two sets of strain data. The correlation between individual strain gauges and gauge 19 may be quantified by a correlation coefficient and may be visualised using scatter diagrams. When the correlation coefficient is high, all strain data points lie close to a straight line, and when there is lower correlation a much greater scatter of data points occurs. Those gauges whose measurements are affected by lateral bending have the lowest correlation coefficients.

In summary then, to determine the effect of the patches on the strain levels the ratios of relative RMS value is used as a measurement quantity. Use of a correlation coefficient and scatter diagrams enable those cases where there is little correlation between the subject gauge and the reference gauge to be identified, and so indicate where comparisons of RMS values will possibly vary significantly.

# 4. Validation of Comparison Procedures

For comparison purposes it is necessary to select only those data sets for which reasonably similar conditions existed during both trials, such as speed, sea state and relative wave heading. After excluding those data sets where speed and heading are not consistent, the remaining sets are grouped according to relative seaway heading. Of these only those with a 'port bow' or 'head' relative seaway heading are suitable for comparison purposes as there are no post-patch trials for starboard or following seas. The number of data sets available for comparison is therefore significantly reduced and the available data sets are listed in Table 1.

To validate the method of comparison the normalised RMS strain values for two pre-patch and two post-patch runs are compared so that any influence of the patch can be eliminated. The RMS values are normalised with respect to the RMS value for gauge 19 for each particular run, and the ratios of the pre-patch runs, 11301645 with 12011521, and the post-patch runs, 05150657 with 05150830, are plotted in Figure 2. A value of 1.0 means that the relative level of strain at that gauge is the same for both trials and any variation from 1.0 is an indication of the error involved using this approach.

*Table 1. Data Sets Used for Pre- and Post-Patch Installation Comparison*

| Rel Wave Dir'n | Pre-Patch | | Post-Patch | |
|---|---|---|---|---|
| | File | Speed, Sea State | File | Speed, Sea State |
| Head | 11301645 | 7 kts, SS5 | 05160753<br>05161014 | 10 kts, SS3-4<br>15 kts, SS 3-4 |
| | 12011521 | 24 kts, SS3 | 05140852<br>05161044 | 18 kts, SS3<br>24 kts, SS3-4 |
| Port bow | 12011048 | 7 kts, SS3-4 | 05150657 | 12 kts, SS5 |
| | 12031916 | 18 kts, SS3 | 05150830 | 15 kts, SS5 |

In Figure 2 most values lie within ± 10% of 1.0 and for the post-patch comparison most are within ± 5%. The results are more widely varied for the pre-patch comparison (11301645:12011521) where there is variation in forward speed of between 7 to 24 knots, and a variation in observed sea state of SS 3 to SS 5. In the post-patch comparison (05150657: 05150830) there is a 3 knot variation in forward speed, the sea conditions are essentially identical as the two runs are only 90 minutes apart. It would seem therefore that the differences in speed and sea conditions have a significant effect on the accuracy of the comparison method, however it is not possible to quantify these effects due to the lack of detailed wave information, particularly directional wave spectra.

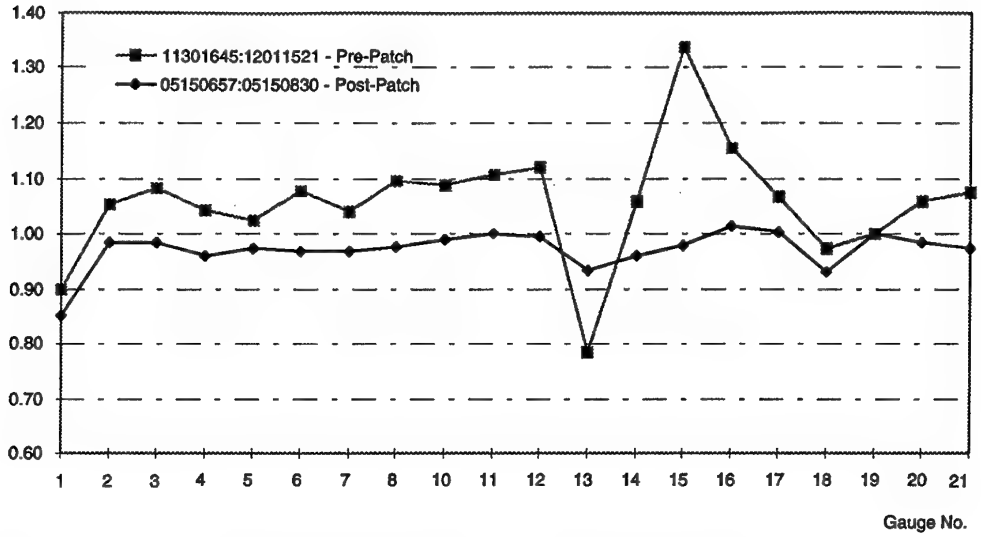



*Figure 2.* *Normalised RMS Strain Ratios without Patch Influence*

Correlation coefficients for the four runs are given in Table 2 and it can be seen that where there is a large variation from 1.0 in Figure 2 there is a corresponding drop in the correlation coefficient. The inverse is however not necessarily true as the correlation coefficients in Table 2 only provide the correlation between two gauges during the same run. The main reason for low correlation between gauges during the same run is believed to be the influence of lateral bending effects which are excluded from the gauge 19 data.

The lack of correlation between gauges 1 and 19 during run 05150830, for example, is clearly demonstrated in the scatter diagram shown in Figure 3. Gauge 1 measures pure lateral bending whereas gauge 19 measures pure longitudinal bending and as can be seen there is little correlation between the two gauges. Gauges 21 and 19 however, which both measure longitudinal bending, have a much greater correlation and so the relationship between the two gauges virtually follows a straight line. It is of interest to note in Figure 3 that strain levels for gauge 19 are approximately half the strain level of gauge 21 at the corresponding time. Gauge 21 measures strain in the hull at the main deck whilst gauge 19 measures strain just above the main deck in the superstructure side shell plating, so the distance of both gauges from the neutral axis is almost the same and so similar strains are expected. The large difference between the two indicates that there is not full transfer of load from the hull to the superstructure, possibly due to shear lag effects.

In Figure 2 gauges 13, 15 and 16 all show a fairly high variations above and below 1.0 and again this is due to the fact that these gauges are not fully correlated with gauge 19, as can be seen in Table 2. These gauges, plus gauge 18, form the ±45° arms of rosettes on the deckhouse sides at the frame 196 knuckle and so measurements are

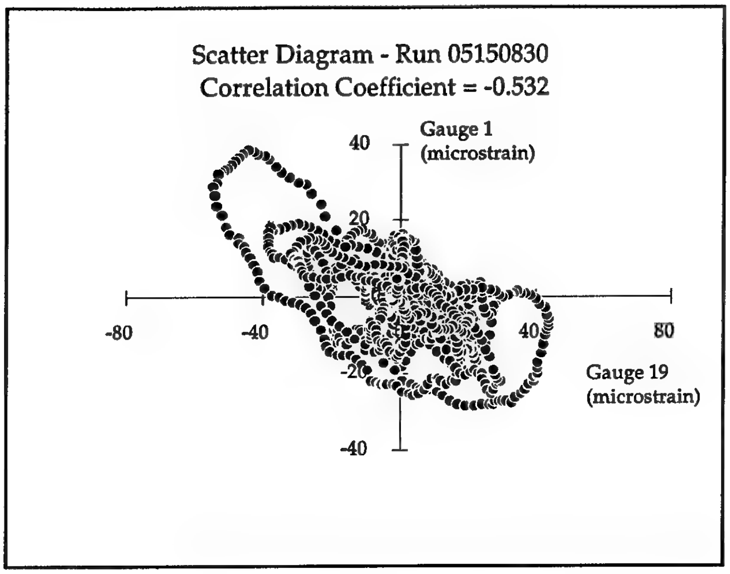
influenced by longitudinal and lateral bending. It is likely that transformation of the rosette strains to principal strains would provide a better result but this facility is not yet available in the computer program used for data analysis.

During the preparations for application of the patch a crack was found on the starboard side of 02 deck at the forward end of the insert plate, i.e. approximately frame 192-193, and was subsequently weld repaired. This will obviously affect the pre- and post-patch comparison unless the crack developed between the time the pre-patch trials were conducted and the application of the patches. It is believed that the crack was present at the time of the pre-patch trials and that this is the cause of the large difference between the results for the starboard rosette (13,14 and 15) and the port rosette (16,17 and 18) in Figure 2.

*Table 2. Correlation Coefficients for Individual Gauges with Gauge 19.*

| Run | 05150657 | 05150830 | 12011521 | 11301645 |
|---|---|---|---|---|
| Gauge No. | | | | |
| 1 | **-0.47771** | **-0.53227** | **-0.02789** | **0.145755** |
| 2 | 0.989005 | 0.987811 | 0.987905 | 0.989207 |
| 3 | 0.998165 | 0.997562 | 0.988366 | 0.997472 |
| 4 | 0.982867 | 0.980891 | 0.920999 | 0.983781 |
| 5 | 0.987168 | 0.985103 | 0.971581 | 0.988132 |
| 6 | 0.993691 | 0.992085 | 0.981934 | 0.992268 |
| 7 | 0.995074 | 0.99381 | 0.982389 | 0.992447 |
| 8 | 0.995961 | 0.995134 | 0.97839 | 0.990915 |
| 10 | 0.998927 | 0.998863 | 0.992385 | 0.997701 |
| 11 | 0.993844 | 0.992681 | 0.989984 | 0.9875 |
| 12 | 0.997428 | 0.997087 | 0.994435 | 0.99562 |
| 13 | **0.657995** | **0.65713** | **0.669151** | **0.521341** |
| 14 | 0.989822 | 0.988091 | 0.979222 | 0.985807 |
| 15 | **0.837247** | **0.846317** | **0.840739** | **0.701645** |
| 16 | **0.915689** | **0.907423** | **0.92825** | **0.898066** |
| 17 | 0.994331 | 0.993547 | 0.990396 | 0.991672 |
| 18 | **0.778828** | **0.768847** | **0.799857** | **0.67816** |
| 19 | 1 | 1 | 1 | 1 |
| 20 | 0.997191 | 0.995811 | 0.996864 | 0.996523 |
| 21 | 0.996087 | 0.995395 | 0.981253 | 0.996216 |

Overall there is a considerable range of conditions encompassed by these comparisons and, exceptions noted, the narrow-bandedness of these results suggests that the methods outlined previously are a valid form of comparison. In cases where gauges are responding in a similar manner to gauge 19 and are not excessively influence by lateral or torsional effects the relative RMS value is an appropriate measurement quantity. However in those cases where there are substantial differences in sea conditions or where gauges respond to lateral and torsional influences, the use of the relative RMS value does not provide totally reliable answers. The use of scatter diagram clearly illustrates the degree, or otherwise, of correlation between individual gauges and the reference gauge.



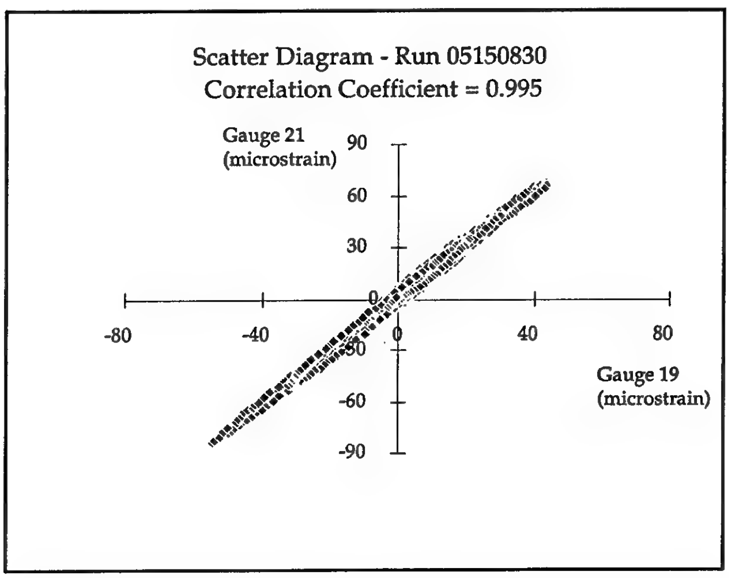




*Figure 3. Scatter Diagrams - Gauges 1 and 21 Plotted against Gauge 19.*

# 5. Comparison of Pre- and Post- Patch Results

The ratios of the post-patch normalised RMS values compared to the pre-patch values for the data sets detailed in Table 1 are presented in Figures 4, 6 and 8. For the first of the head seas comparisons (Figure 4) the two curves are virtually identical which indicates that the effect of the patch is the same for both comparisons. The two sets of post- patch data were recorded only 2 hours apart so the sea conditions are reasonably similar and there is only a 5 knots difference in ship's speed. The only notable difference between the two curves is gauge 21 and the reasons for this were explained earlier. The reason for the large difference between the results for gauges 4 and 5 (which are respectively below and above the 02 deck) is not known but there is a consistent difference throughout and it is probably a result of the weld repair.

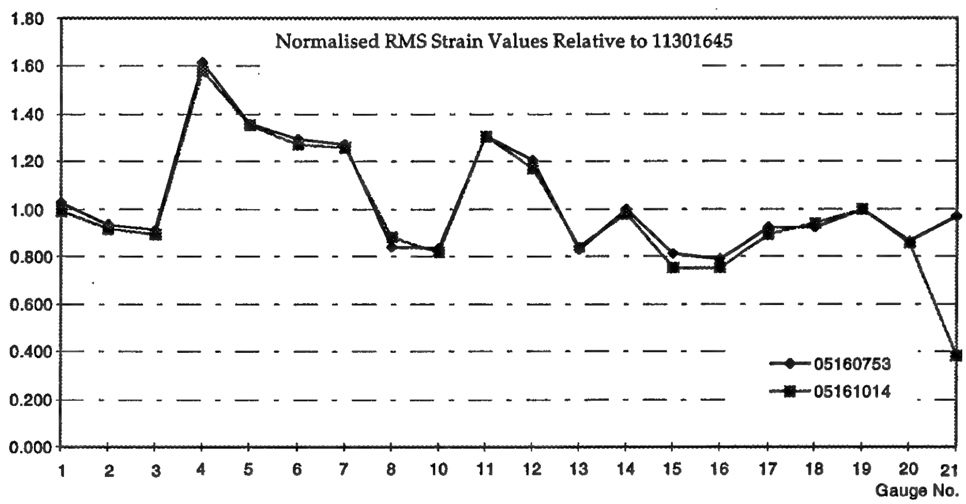



*Figure 4. Change in Relative Normalised RMS Levels - Head Seas Case 1 (Values greater than 1.0 indicate an increase in post-patch level)*

The differences between gauges 4 and 11 and between 6 and 12 indicates that there is a greater post-patch change in strain levels on the starboard side. This is due to the weld repair of the crack in 02 deck at the time of the patch installation . The crack was present during the pre-patch trials as seen in Figure 5 where the pre-patch strain levels for gauge 4 are approximately 50% of those for gauge 11, while for the post-patch they are almost identical. On the relative basis used for comparison the post-patch results for the starboard gauges 4 and 6 are therefore significantly higher.

In the second of the head seas comparisons, Figure 6, the results vary quite substantially. The curve for run 05161044 is quite similar in shape and magnitude to the values plotted in Figure 4 while the curve for 05140852 is markedly different. Strain spectra and scatter diagrams have been produced for many of the cases

presented in Figure 6 but these have provided no insight as to why there is such large variability between the two curves. It is believed that the main reasons for this are that drift in the mean strain level and the influence of lateral bending have relatively greater influence due to the low strain levels recorded during run 05140852. An increase in lateral bending of around 70% for gauge 1 in run 05140852 suggests that lateral bending should have greater influence than for other runs.

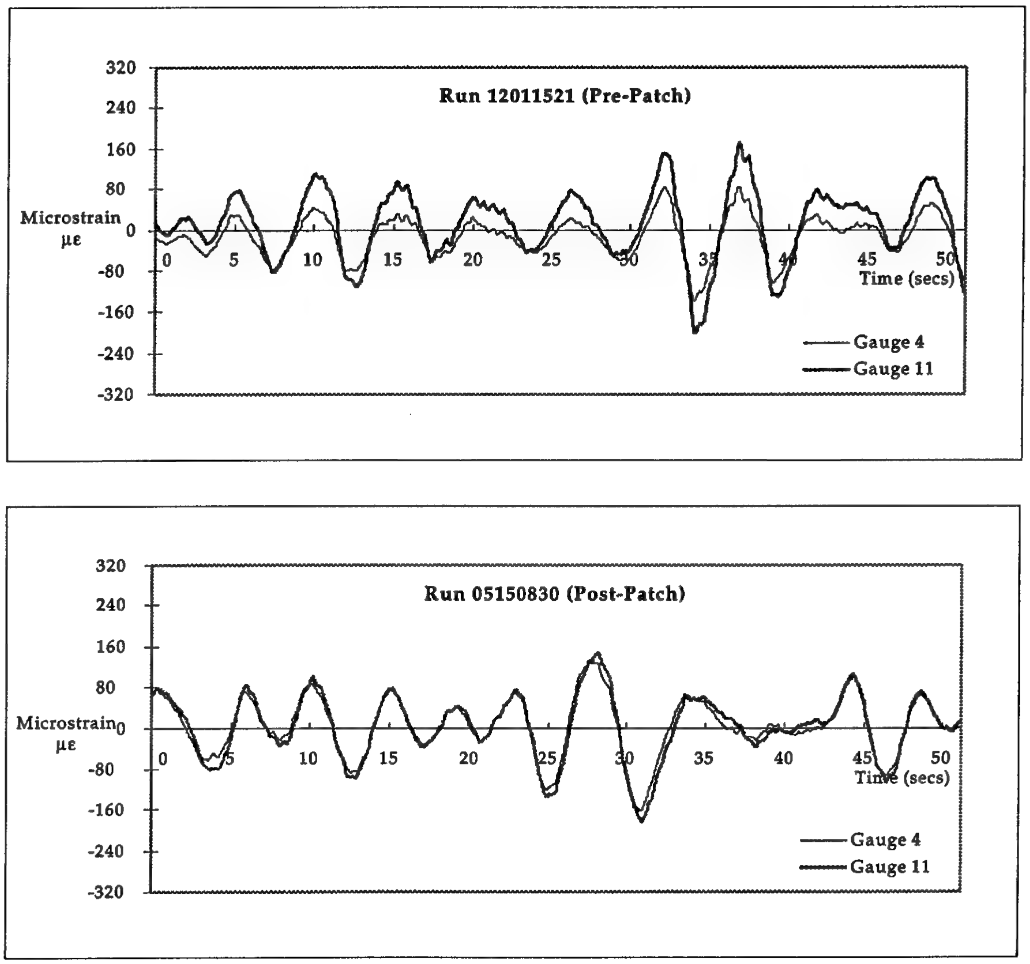



*Figure 5. Strain Time Histories Gauges 4 & 11 Before and After Weld Repair to 02 Deck*

Figure 7 shows the first 50 seconds of the strain time histories for gauges 14 and 17 which form the horizontal arms of the rosettes on either side of the ship at frame 196. It is seen that the levels of strain are very low and that the lateral bending (the average of the difference between the two gauges) is about 15% to 20% of the total recorded strain. The two strain records are also offset from one another with the gauge 14 record

obviously not symmetric about zero. Since the strain record has been numerically adjusted to give a zero mean (based on a larger time duration than that shown in Figure 7) the offset shows that mean value over a short period of time is somewhat different from the mean for the total record. This is an indication of either instrument drift or changing conditions during the trial.

The actual levels of strain recorded during run 05140852 are significantly lower than other runs. While strain levels are relatively low for all runs considered in this report, the levels for 05140852 are typically only around 20% of the value of other cases and as seen in Figure 7 there is a relatively high background noise level. RMS values for gauges 13 through 21 are generally the lowest of the RMS values for each run, and for gauge 19 in run 05140852 the actual RMS value is only 2.234με. In terms of digitising error alone this means that a one bit error during the digitising process may result in an error of approximately 10% of the RMS value.

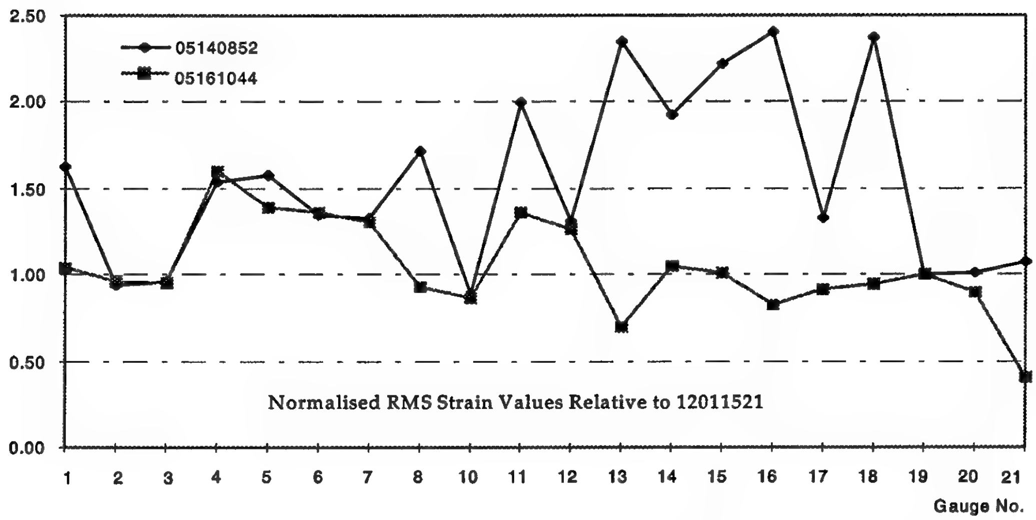



*Figure 6. Change in Relative Normalised RMS Levels - Head Seas Case 2 (Values greater than 1.0 indicate an increase in post-patch level)*

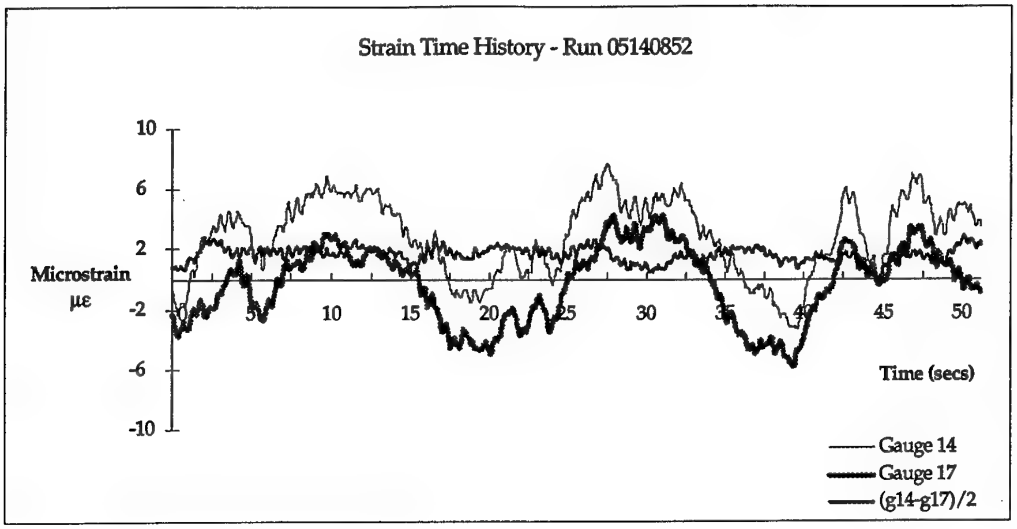



*Figure 7. Strain Time History Gauges 14 and 17 Showing Lateral Bending Component*

It is concluded therefore, that because of the low strain levels the background noise, signal drift and lateral bending have a much greater overall influence on the results for run 05140852 and so the results for this run do not provide a reliable estimate of the effects of the patches.

The port bow seas comparisons from Table 1 are both shown in Figure 8 and while the two cases are not identical they show similar results for many gauges and the shapes of the curves are for the main similar to those in Figure 5. The comparison 05150830:12031916 generally shows higher increases in relative RMS values than does 05150657:12011048 although variations from 1.0 are generally smaller than those for the head seas case (Figure 5). The greatest differences between the two comparisons are for gauges 7, 11 and 13 where the relative changes are in opposite directions. For the comparison 05150830:12031916 there is an increase in relative stress levels while for 05150657:12011048 reduced strain levels are indicated. The levels of strain recorded during run 12031916 are quite low in comparison to other runs in Figure 8 so the results are likely to be affected for similar reasons to that detailed above.

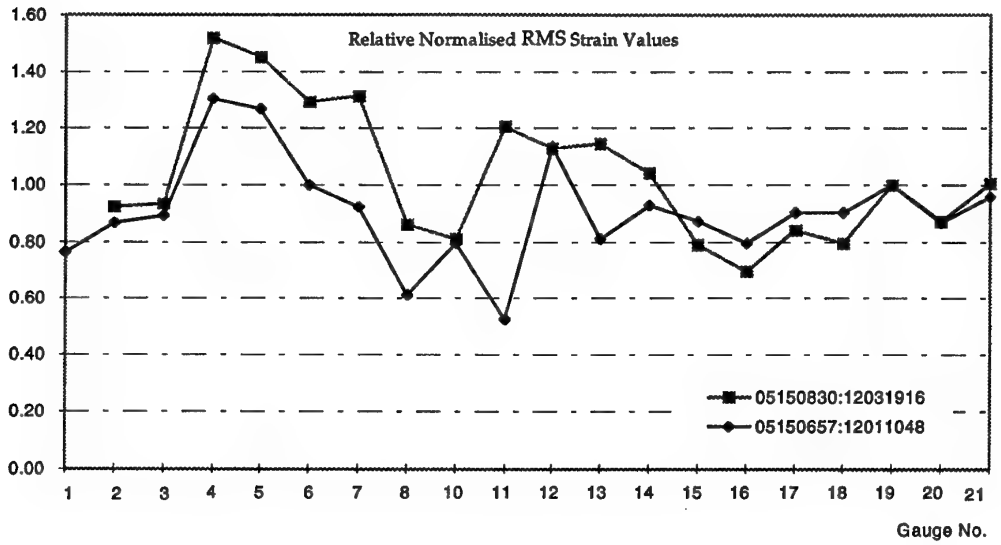



*Figure 8. Change in Relative Normalised RMS Levels - Port Bow Seas (Values greater than 1.0 indicate an increase in post-patch level)*

# 6. Discussion

The analysis has been restricted by the lack of detailed sea state information which has meant that no information relating to the actual loading of the vessel is available. To determine the changes in strain levels it has been necessary to assume that strains at monitored locations change in proportion to a reference gauge, and that these changes can be quantified in terms of normalised RMS strain values. While the normalised RMS value appears to be an appropriate quantity with which to determine the effects of the patches, it is seen that results are influenced by the low levels of strain recorded during the trials, non-linearity resulting from differences in sea conditions, ship speed and relative heading, and poor correlation between individual gauges and the reference gauge. In such cases the use of the relative RMS values does not always provide an entirely satisfactory means of comparison. For the conduct of future trials it is recommended that reference gauges be chosen so as to provide the best possible signal, for example a reference gauge on the keel centreline girder would have been preferable for the current analysis as it would have provided a larger signal and would be less likely influenced by the patch installation.

The preceding results display certain trends which indicate the effects of the patches at the monitored locations but the results are not consistent across all results and the reasons for these inconsistencies not always identifiable. Nevertheless the trends are sufficient to allow some quantitative assessment of the effects of the patches. The average value of the normalised relative RMS values, excluding run 05140852, given in

Figures 4,6, and 8 above are plotted in Figure 9 and are shown diagrammatically in Figure 10. The results for gauge 21 relating to runs 05161014 and 05161044 are considered anomalous and so as not to distort the average these are excluded from Figures 9 and 10.

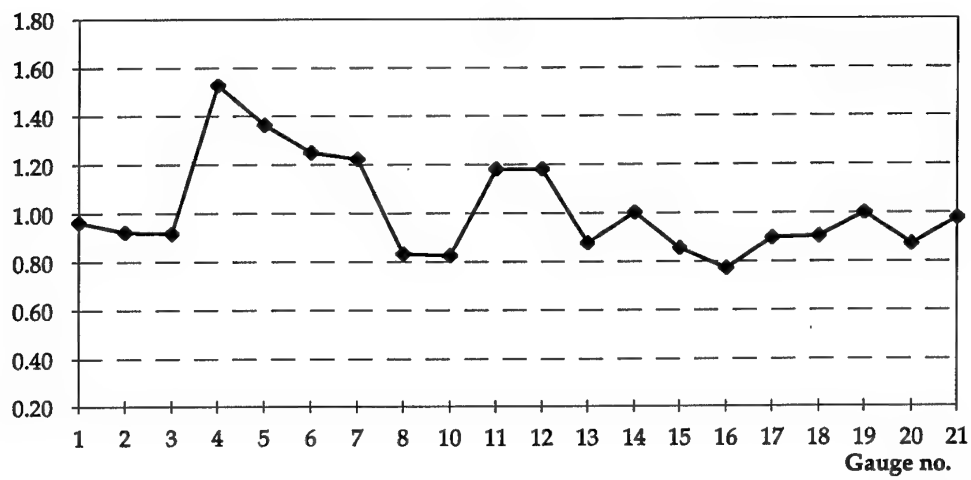



*Figure 9.. Average Relative Normalised RMS Changes (Excluding Run 05140852) (Values greater than 1.0 indicate increase in post-patch level)*

The results have been influenced by several external factors which are difficult to quantify in any definite way. The variation between sea conditions for individual trials appears to have reasonable impact on the results, although it is not likely to be more than a few percent. The presence of strains caused by lateral bending causes some inconsistent results. A weld repair carried out just prior to the patch installation has distorted the results for those gauges nearest the starboard patch, particularly gauges 4 to 7. Strain levels for run 05140852 are much lower than for other runs and so non-linear effects and other forms of error have significantly greater effect than in other cases considered, as a result show much larger variations from the baseline position are indicated. Likewise results for run 12031916 are similarly affected but not to the same extent. In spite of these factors it is expected that the results presented in figures 9 and 10 are probably accurate to within 5% to 10% except for those locations particularly influenced by the weld repair.

Gauge 1 results are difficult to assess with any confidence because of the lack of correlation between lateral and longitudinal bending. The lateral bending mode has been shown to have virtually no correlation with the longitudinal bending mode and so assessment based on the above results is risky. Because of the increased section inertia provided by the patches there is likely to be a small drop in strain levels, however this drop will only be small, and from Figure 9 this seems to be the case.

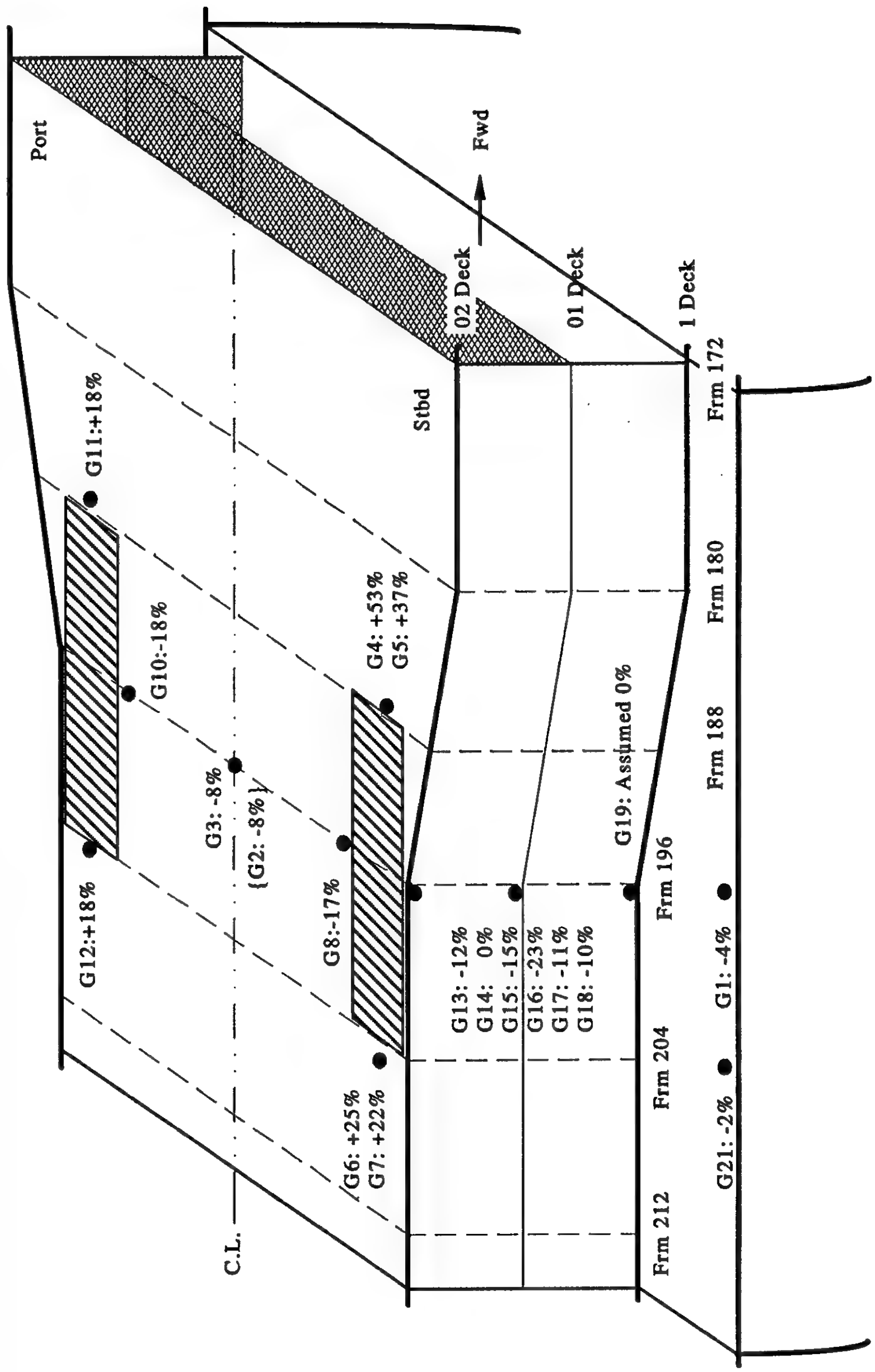



*Figure 10. Average Changes in RMS Strain - Relative to Pre-Patch Levels*

Longitudinal bending strains are measured by gauges 2 and 3, located at frame 201 on the ship's centreline on 01 and 02 deck respectively and gauges 20 and 21 which also measure longitudinal strains by averaging port and starboard strains at 02 and 1 deck levels respectively. The results show that the patches have the effect of providing a small reduction in longitudinal bending strains, around 5% to10%, at these locations. It is likely therefore that the patches have had some effect on the level of strain at 1 deck level and so assumption that gauge 19 is unaffected by the patches will involve some error.

Gauges 4, 5, 6, 7, 11 and 12 which are located on the upper and undersides of 02 deck along the patch centrelines, show increases of between 20% and 60% from the pre-patch to the post-patch trials. An increase in strain at these locations is to be expected as the load carried by the patch must be dissipated into the deck at either end of the patch and so the strains in these locations will increase. The largest increases appear to occur during the head seas cases. The asymmetry between port and starboard results is believed to be due to the weld repair of a crack on the starboard side of 02 deck at Frame 192-193 just prior to the application of the patches. Gauges 4 and 5 seem to be most affected by the weld repair, although the slightly greater post-patch relative strain levels for gauges 6 and 7 compared with gauge 12 show that these gauges are also affected.

Gauges 8 and 10 measure strains alongside the mid-span of the patches and are located on the underside of 02 deck inboard of the patches. There is a reduction in strain levels of around 10%-20% at these locations and again although the gauges are located at nominally identical positions on either side of the ship and their results are similar in most instances, post patch strain levels are often lower for gauge 10 (port side). However the results are not consistent, for example run 05150657 shows a 40% reduction for gauge 8 and not for gauge 10, while for run 05140852 there is an apparent 60% increase for gauge 8 but not for gauge 10.The results for the rosettes located at the frame 196 knuckle (gauges 13, 14, 15 and 16, 17, 18) are erratic with sometimes large variations between results across different trials, although on average a reduction of up to 23% is indicated. Results would probably be clearer if the rosette strains were converted to principal strains for the comparison, however the analysis software requires modification before this can be done. Results for the starboard side show about a 5% greater strain reduction compared to the port side. It is likely therefore that the results are influenced by both the patch and the weld repair on 02 deck, and that the patches have produced a reduction of up to 15% in some cases, although for principal strains this is would likely be lower.

It has been possible therefore to broadly quantify the effects of the patches on superstructure strain levels at the monitored locations although the results are not always consistent, particularly in cases where strain levels are very low. Generally there has been a reduction in strain levels of around 10% to 15% alongside and away from the patches while there has been an increase of about 20% immediately next to either end of the patches. The patches are therefore an effective means of reducing the strains, and hence stresses, at the midspan of the patches and in other areas around

Frame 196 at the forward end of the necked region of the superstructure, and of transferring the load to the ends of the patches. The results are different for each patch due to weld repairs of a crack on the starboard side of 02 deck, resulting in much larger changes in strain levels on the starboard side. An analytical analysis using the Finite Element Method would allow the effects of the patches on stress levels to be studied more closely, and would enable future repairs to be tailor made so as to reduce the increase in stresses at the ends of the patches.

# 7. Conclusions and Recommendations

An analysis method to assess the effect of bonded repairs to an RAN FFG-7 Frigate superstructure has been proposed and validated and an analysis of the trials data has been conducted. While the analysis has been restricted by the lack of detailed sea state information, it has been possible to broadly quantify the effects of the patches on superstructure strain levels:

- There has been a reduction in strain levels in 02 deck of around 10% to 15% adjacent to the midspan of the patches and in other areas around Frame 196 and an increase of about 20% immediately next to either end of the patches.

- The patches are an effective means of reducing the strains, and hence stresses, in the region where the patches are applied and of transferring the load to the ends of the patches.

- The results vary for each patch due to weld repair of a crack on the starboard side of 02 deck which was carried out between the strain measurement trials. Much larger changes in strain levels are therefore indicated on the starboard side.

The analysis has also highlighted areas of further analysis and certain aspects of trials procedure which could be modified during the conduct of further trials:

- Trials need to be conducted in heavy weather so as to ensure suitably high levels of strain are obtained and a dedicated trials period is needed to ensure that the best possible information is obtained during the trials.

- Directional wave height spectra should be obtained whenever possible so as to enable maximum utilisation of the recorded data. If it is not possible to obtain wave height spectra then reference gauges need to be chosen so as to provide the best possible signal.

- Signal recorder voltage windows need to be monitored and adjusted during trials so as to minimise resolution errors.

- Further enhancements to the data analysis software are required, namely transformation of rosette strains to principal strains, filtering of background noise and correction for low frequency drift.

- An analytical analysis, using the Finite Element Method, to enable patches to be tailor made so as to minimise any stress increases is strongly recommended.

# 8. Acknowledgments

Thanks are extended to the RAN and the crew of HMAS SYDNEY for their assistance during the strain gauging trials, and to Messrs Phillip Box and Jeff Lingard who conducted the trials.

# 9. References

1. Grabovac I., Pearce P.J., Baker A.A., and Bartholomuez R.A., "Carbon Fibre Composite Reinforcement of Aluminium Superstructure", Ninth International Conference on Composite Materials (ICCM-9), Madrid, Spain, July 1993.

2. Grabovac I., Bartholomuez R.A., and Baker A.A., "Composite Reinforcement of a Ship Superstructure - Project Overview", Composites 24 (6) 501-509, 1993.

3. Grabovac I., Pearce P.J., et al, "In-Situ Carbon Fibre Reinforcement of Uneven Warship Structure, I. Resin Development, II. Composite Development, III. Application to an FFG-7 Class Frigate", Under preparation for submission to Composites.

BONDED REPAIRS TO RAN FFG SUPERSTRUCTURE-
STRAIN GAUGE DATA ANALYSIS

# APPENDIX A.
## Gauge Locations and Trials Summary

*Table A1. Strain Gauge Locations*

| Bridge/ Gauge No. | Frame | Deck | Location | Comments |
|---|---|---|---|---|
| 1 | 196 | 1 | P&S(S) | Full Br. - Lat Bending (Port tension/Stbd Comp +ve), 4" fwd Fr 196 (on longitudinal stiffeners) |
| 2 | 201 | 01 | C.L.(U) | Half Br - underside of 01 deck on C.L. longitudinal at frm 201 |
| 3 | 201 | 02 | C.L.(U) | Half Br - directly above gauge 2 on N.A. of C.L. longitudinal |
| 4 | 188 | 02 | Stbd(U) | Half Br - 2.5" fwd of frm 188, along c.l. of patch, underside of deck |
| 5 | 188 | 02 | Stbd(A) | Half Br - 2.5" fwd of frm 188, on c.l. of patch, external deck surface |
| 6 | 204 | 02 | Stbd(U) | Half Br - 2.5" aft of frm 204, on c.l. of patch, underside of deck |
| 7 | 204 | 02 | Stbd(A) | Half Br - 2.5" aft of frm 204 , on c.l. of patch, external deck surface |
| 8 | 200.5 | 02 | Stbd(U) | Half Br - Underside of deck, 2" inboard of patch |
| 9 | 200.5 | 02 | C.L.(U) | Gauge Failed |
| 10 | 200.5 | 02 | Port(U) | Half Br - Underside of deck, 2" inboard of patch |
| 11 | 188 | 02 | Port(U) | Half Br - 2.5" fwd of Frm 188 and along c.l. of patch underside of deck |
| 12 | 204 | 02 | Port(U) | Half Br - 2.5" aft of Frm 204 and on c.l. of patch underside of deck |
| 13 | 196 | 01 | Stbd(S) | Rosette -4" fwd frm 196, 45° above H.A. Deckhouse side at knuckle |
| 14 | 196 | 01 | Stbd(S) | Rosette -4" fwd frm 196, along H.A. Deckhouse side at knuckle |
| 15 | 196 | 01 | Stbd(S) | Rosette -4" fwd frm 196, 45° below H.A. Deckhouse side at knuckle |
| 16 | 196 | 01 | Port(S) | Rosette -4" fwd frm 196, 45° above H.A. Deckhouse side at knuckle |
| 17 | 196 | 01 | Port(S) | Rosette -4" fwd frm 196, along H.A. Deckhouse side at knuckle |
| 18 | 196 | 01 | Port(S) | Rosette -4" fwd frm 196, 45° below H.A. Deckhouse side at knuckle |
| 19 | 196 | 1 | P&S(S) | Full Br. - Long Bending, 4" fwd frm 196, deckhouse side |
| 20 | 196 | 02 | P&S(S) | Full Br. - Long Bending, 4" fwd frm 196, deckhouse side |
| 21 | 204 | 1 | P&S(S) | Full Br. - Long Bending, approx frm 201, underside of deck |

P&S - Port and Starboard C.L. - Ship Centre Line N.A. - Neutral Axis
(U) - Underside of deck (A) - Above deck (S) - Superstructure/Hull side shell plate

*Table A2. Summary of Pre-Patch Trials*

| Filename | Ship Speed | Rel Heading | Sea State | Comments |
|---|---|---|---|---|
| | | | | |
| 11301130 | 20 | stbd bow | 4 | Consistent speed and heading |
| 11301320 | | | | Firing 76mm gun, 2*5 round bursts |
| 11301525 | 0 | port bow | 4 | Turned to following seas |
| 11301615 | | | 4 | Numerous course and speed changes |
| 11301645 | 7 | head | 5 | Consistent speed and heading |
| 11302008 | 8-12 | head | 5 | Changed to 5 kts after 9 mins |
| 11302038 | 5-7 | | 5 | Head seas followed by numerous course changes |
| 12010755 | 10-15 | 180 | 4 | Changed to 15 knots 5 mins into run |
| 12010842 | 18-22 | head | 4 | For 6 mins into run then 13 kts port bow seas |
| 12010912 | | head | 4 | 76mm gun firings (40f) 1-2 min into run |
| 12011048 | 7 | port bow | 3-4 | Consistent speed and heading |
| 12011521 | 24 | head | 3 | Consistent speed and heading |
| 12011552 | 20 | head | 3 | Head seas for 17 mins then variable |
| 12011622 | 20 | port beam | 3 | Port beam seas for first 22 mins then to following seas |
| 12021111 | 16 | port beam | 1 | Port beam seas for 19 mins then slow course change to give stbd beam seas |
| 12021330 | | | 1 | Numerous course and speed changes |
| 12031653 | 10 astern | port quarter | 3 | Ran 10 knots astern for first 17 mins, then forward |
| 12031808 | 20 | various | 3 | Head sea for 15 mins then changes |
| 12031916 | 18 | port bow | 3 | Consistent speed and heading |
| 12031950 | 12 | port bow | 3 | Port bow seas for first 13 mins then changes |

*Table A3. Summary of Post-Patch Trials*

| Filename | Ship Speed | Rel Heading | Sea State | Comments |
|---|---|---|---|---|
| | | | | |
| 12051714 | 21 | following | 1 | Wind chop was following but the ship was head on to a small swell |
| 05140852 | 18 | head | 3 | Consistent speed and heading |
| 05150618 | 8-12 | head | 5 | 16 min. into run change to port bow seas & 10 knots. 20 min into run speed to 12 knots |
| 05150657 | 12 | port bow | 5 | Consistent speed and heading |
| 05150830 | 15 | port bow | 5 | Consistent speed and heading |
| 05151129 | 4 | head | 3 | Inside Jervis Bay. Swells through the heads on the port bow from 5 to 15 minutes into the run. |
| 05160753 | 10 | head | 3/4 | Consistent speed and heading |
| 05161014 | 15 | head | 3/4 | Consistent speed and heading |
| 05161044 | 24 | head | 3/4 | Consistent speed and heading |

Bonded Repairs to RAN FFG Superstructure-Strain
Gauge Data Analysis

B.P. Phelps

(DSTO-RR-0046)

DISTRIBUTION LIST

Director, AMRL
Chief, Ship Structures and Materials Division
Dr J. Ritter
Mr B.P. Phelps
Mr P. Pearce (Task Manager)
SSHIPLOG (Task Sponsor)
Library, AMRL Maribyrnong
Library, AMRL Fishermens Bend

Chief Defence Scientist (for CDS, FASSP, ASSCM) 1 copy only
Head, Information Centre, Defence Intelligence Organisation
OIC Technical Reports Centre, Defence Central Library
Officer in Charge, Document Exchange Centre 8 copies
Air Force Scientific Adviser, Russell Offices
Senior Defence Scientific Adviser / Scientific Adviser - Policy and Command 1 copy
Senior Librarian, Main Library DSTOS
Librarian, DSD, Kingston ACT
Serials Section (M List), Deakin University Library, Deakin University, Geelong 3217
NAPOC QWG Engineer NBCD c/- DENGRS-A, HQ Engineer Centre, Liverpool Military Area, NSW 2174
ABCA, Russell Offices, Canberra ACT 2600 4 copies
Librarian, Australian Defence Force Academy
Head of Staff, British Defence Research and Supply Staff (Australia)
NASA Senior Scientific Representative in Australia
INSPEC: Acquisitions Section Institution of Electrical Engineers
Head Librarian, Australian Nuclear Science and Technology Organisation
Senior Librarian, Hargrave Library, Monash University
Library - Exchange Desk, National Institute of Standards and Technology, US
Acquisition Unit (DSC-EO/GO), British Library, Boston Spa, Wetherby, Yorkshire LS23 7BQ, England
Library, Chemical Abstracts Reference Service
Engineering Societies Library, US
Documents Librarian, The Center for Research Libraries, US
Army Scientific Adviser, Russell Offices - data sheet only
Navy Scientific Adviser - data sheet only
Director General Force Development (Sea)
ASSTASS PD, CP3-4-12, Campbell Park Offices, Canberra ACT - data sheet only
SO (Science), HQ 1 Division, Milpo, Enoggera, Qld 4057 - data sheet only
Librarian - AMRL Sydney - data sheet only
Counsellor, Defence Science, Embassy of Australia - data sheet only
Counsellor, Defence Science, Australian High Commission - data sheet only
Scientific Adviser to DSTC Malaysia, c/- Defence Adviser - data sheet only
Scientific Adviser to MRDC Thailand, c/- Defence Attache - data sheet only

Manager In Service Design, Remington Centre (2 copies)
Director of Naval Architecture, Campbell Park (2 copies)
Commanding Officer - HMAS SYDNEY
Commanding Officer - HMAS ADELAIDE
Commanding Officer - HMAS CANBERRA
Commanding Officer - HMAS DARWIN

| REPORT NO. | AR NO. | REPORT SECURITY CLASSIFICATION |
|---|---|---|
| DSTO-RR-0046 | AR-009-266 | UNCLASSIFIED |

TITLE

Bonded repairs to RAN FFG superstructure-strain gauge data analysis


AUTHOR(S)
B.P. Phelps

CORPORATE AUTHOR
DSTO Aeronautical and Maritime Research Laboratory
PO Box 4331
Melbourne Victoria 3001


| REPORT DATE | TASK NO. | SPONSOR |
|---|---|---|
| June 1995 | NAV 94/001 | SSHIPLOG |
| FILE NO. | REFERENCES | PAGES |
| 510/207/0329 | 3 | 29 |

CLASSIFICATION/LIMITATION REVIEW DATE

CLASSIFICATION/RELEASE AUTHORITY
Chief, Ship Structures and Materials Division

SECONDARY DISTRIBUTION

Approved for public release

ANNOUNCEMENT

Announcement of this report is unlimited


KEYWORDS

| | | |
|---|---|---|
| Adhesive Bonding | Fracture Mechanics | Superstructures |
| Carbon Fiber Reinforced Composites | Strain Gages | Bonded Composite Repairs |
| HMAS SYDNEY (1983) | Strain Measurement | Sealing |
| HMAS FRIGATE | Weldments | Composite Materials |
| Metal Fatigue | | |



ABSTRACT

Two adhesively bonded carbon fibre patches have been applied to the upper deck of HMAS SYDNEY, an FFG7 Class Frigate, to determine their effectiveness in overcoming fatigue cracking problems in the aluminium superstructure. Strain measurement trials were conducted before and after the patch application to determine their effect on stress levels in the superstructure. An analysis procedure based upon the relative normalised RMS strain value is proposed and validated, and is then used to assess the effects of the patches. A reduction in strain levels is observed along the sides of the patches and in other areas in the necked region of the superstructure, while there is an increase next to either end of the patches. The patches are seen as an effective means of reducing stresses at areas of higher stress and of transferring the load to the ends of the patches where stresses are lower. The effect of a weld repair to a crack on the starboard side of 02 deck, which was affected between the two strain measurement trials, is seen to cause much larger changes in relative strain levels on that side of the ship. Recommendations in relation to the conduct of further trials are provided, including; the need to conduct in high sea states to ensure suitably strain high levels, a dedicated trials period, the need to obtain directional wave height spectra and enhancements to the data analysis software. Further analysis using the Finite Element Method is also recommended.

DISTRIBUTION LIST (Contd)

Commanding Officer - HMAS MELBOURNE
Commanding Officer - HMAS NEWCASTLE
Australian Defence Industries (Naval Engineering Division), Garden Island Dockyard, Sydney (Attn: Mr J. Benjamin)
Platform Manager Surface Ships (Attn: Mr E. Schweiger, Remington Centre) (3 copies)
Principal Naval Representative (ADI), Garden Island Dockyard
FFG PUP Project (Remington Centre)
MHQ & FHEO (Attn: CMDR J. Carlin)
ABCA-11 Members -
DREA (2 copies) )
DERA (1 copy) ) c/- author
NAVSEA (1 copy) )
AMRL (2 copies) )